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Implementation of the soil health monitoring system to achieve better yield

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ABSTRACT

Agriculture is a fundamental pillar of the economy, particularly in developing countries where a significant proportion of the population depends on farming for their livelihood. Crop productivity is influenced by soil type and its changing chemical properties. A lack of understanding of soil health, crop-specific nutrient requirements, and the interaction between water and the environment often leads to inappropriate irrigation and fertilizer use. As a result, crops receive either excessive or insufficient nutrients, leading to reduced yields and the waste of water, energy, and other valuable resources. To address these issues, this paper presents an IoT-based soil health monitoring system that supports sustainable crop management. The proposed system integrates sensors to monitor key soil parameters such as temperature, humidity, soil moisture, and pH levels in real time. Based on the collected data, the system autonomously adjusts irrigation and environmental conditions to maintain soil health. This approach improves crop productivity, optimizes resource utilization, and promotes energy conservation in agricultural systems.

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1. INTRODUCTION

Agriculture is a vital sector, providing food, raw materials, and economic stability worldwide [1]. Globally, about 60% of the population depends on agriculture, and in India, it is the primary livelihood for approximately 55% of the population [2]. The country's diverse agro-climatic conditions and natural resources offer a competitive advantage in food production and processing. Agriculture contributes around 4% to the global GDP, and in some least-developed countries, it accounts for more than 25% [2], [3]. Beyond food production, it is central to poverty reduction 65% of poor working adults earn their income through farming, which is significantly more effective at improving livelihoods than growth in other sectors [4].

Soil type is a key determinant of agricultural productivity, with each type, such as alluvial, red, black, or sandy soil, best suited for specific crops [5]. However, factors like erosion, fertility depletion, monocropping, and climate variability reduce productivity. Many farmers, especially new entrants to agriculture, lack adequate knowledge of soil quality, crop suitability, and the required climatic conditions. This knowledge gap affects crop yield and overall agricultural sustainability.

Climate change further complicates farming by altering temperature, rainfall, and humidity patterns, directly impacting crop yields [6]. Meeting the growing food demand projected to increase by 1.4% annually requires sustainable practices that ensure high yields under changing conditions. To achieve this, farmers need timely and accurate information on soil health and environmental parameters.

Wireless sensor networks (WSNs) and internet of things (IoT) technologies offer real-time monitoring of key parameters such as soil moisture, temperature, humidity, pH, light, and rainfall [7]. These systems provide actionable data that help farmers make informed decisions on irrigation, fertilization, and crop selection, thereby optimizing resource use, improving yields, and reducing environmental impact. Unlike conventional monitoring, WSNs enable continuous, remote data collection and automated control actions, minimizing human intervention and ensuring timely responses to sudden environmental changes [8].

The proposed system builds upon these advances by not only monitoring environmental and soil parameters but also automating protective and corrective measures. For instance, in the event of heavy rainfall, an automated shutter mechanism can protect sensitive crops from damage [9]-[11]. The novelty of this work lies in integrating crop-specific recommendations based on prevailing climatic conditions with automated actuation to safeguard crops during growth, ensuring maximum yield despite unpredictable environmental variations [12], [13].

From the discussion, it is evident that soil is a vital natural resource and serves as the fundamental medium for crop production. The ability of soil to supply nutrients, retain moisture, and sustain biological activity determines the overall health and yield potential of crops. However, in recent decades, intensive agricultural practices, indiscriminate use of chemical fertilizers, and unsustainable land management have led to severe soil degradation, nutrient imbalances, and declining productivity. To address these challenges, implementing a soil health monitoring system has become a necessity rather than an option.

A systematic monitoring system enables the continuous assessment of critical soil parameters, such as pH, moisture levels, light, and temperature. Real-time and accurate soil data not only guide farmers in adopting site-specific water management practices but also help reduce the overuse of inputs, thereby improving resource-use efficiency. Furthermore, soil health monitoring provides early warning signals of contamination, compaction, or erosion, allowing timely interventions to restore soil fertility.

The integration of soil health monitoring with modern technologies, such as IoT sensors and data analytics, provides a scientific basis for precision farming. This ensures better crop planning, enhanced yield, and improved profitability while safeguarding long-term soil sustainability. Thus, the implementation of a soil health monitoring system is imperative for achieving higher productivity, reducing environmental impacts, and meeting the increasing global demand for food security.

This study examines the design, implementation, and advantages of an IoT-based soil health monitoring and control system, highlighting its potential to enhance productivity, promote sustainable agriculture, and strengthen food security. A graphical representation of the same is given in Figure 1. The proposed architecture integrates a sophisticated multi-sensor array to monitor critical environmental variables, including soil pH, moisture, and atmospheric conditions. By leveraging satellite telemetry to bridge the gap between remote fields and centralised data processing units, the system ensures real-time oversight of crop health. This end-to-end framework enables agricultural experts to provide data-driven interventions to stakeholders. Ultimately, the system transforms raw field data into actionable insights, mitigating crop failure and optimising soil conditions to achieve significantly better yields.

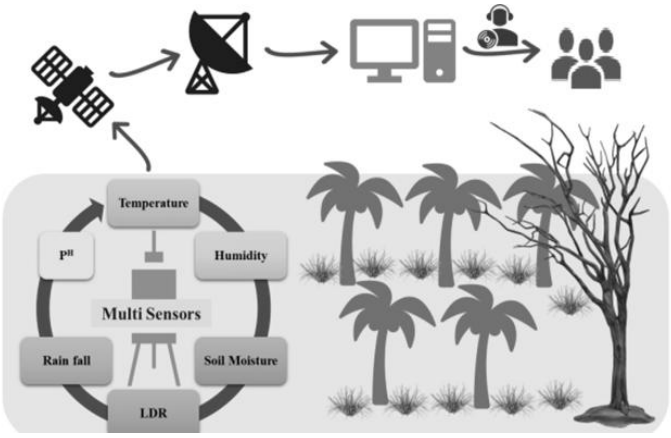

Figure 1. Graphical abstract

2. LITERATURE SURVEY

Several studies have highlighted the challenges faced in the agricultural sector, particularly regarding the labour force and the need for effective monitoring systems to improve crop yield [14], [15]. Table 1 presents data that demonstrate the growth rate and trends in agricultural employment over the years. In 1951, the growth rate was 1.25%, while in 2011, it increased to 1.64%. However, over 60 years, the growth rate was only 0.39%. Despite this minimal growth rate, the number of agricultural labourers increased significantly. In 1951, there were 97.2 million agricultural labourers for a population of 361.1 million. In contrast, in 2011, there were 262.9 million agricultural labourers for a population of 1210.2 million. This indicates a substantial increase in the labour force, while the growth rate remained relatively low, leading to a significant gap.

Table 1. Agricultural growth rate and population

Year	Population (in million)	Average (in million)	Rural (in million)	Agricultural workers (in million)		
				Cultivator	Agricultural labours	Total
1951	361.1	1.25	298.6	69.9	27.3	97.2
1961	439.2	1.96	360.3	99.6	31.5	131.1
1971	548.2	2.2	439	78.2	47.5	125.7
1981	683.3	2.2	523.9	92.5	55.5	148
1991	846.4	2.14	628.9	110.7	74.6	185.3
2001	1028.7	1.95	742.6	127.3	406.8	234.1
2011	1210.2	1.64	833.1	118.6	144.3	262.9

Table 2 further highlights the issue by comparing population and agricultural employment data. In 2001, the population was 1028.7 million, with agricultural employment at 262.5 million. However, in 2010, the population increased to 1210.2 million, while agricultural employment decreased to 236.1 million. This demonstrates a decline in agricultural employment despite population growth, further exacerbating the issue. The decrease in agricultural employment and the declining share of employment in the sector can be attributed to physical parameters, climatic conditions, and a lack of knowledge. As employment decreases, productivity declines, leading to a gap between demand and supply and food scarcity for those in need [16], [17]-[20]. Regarding research and solutions, Liu [16] and the team have designed a wireless monitoring system for temperature and humidity using ZigBee technology. This system aimed to provide accurate and convenient measurement of environmental parameters through wireless sensor networks, allowing for appropriate actions based on the collected data [21].

Table 2. Agricultural employment across different states

States	Agricultural employment (in millions)				Share of employment (%)	
	2004-05		2009-10		2004-05	2009-10
	Agricultural sector	Total sector	Agricultural sector	Total sector	Agricultural sector	Agricultural sector
AP	20.5	38.8	20.4	39.9	52.8	51.2
Assam	7.7	10.8	6.9	10.9	71.3	62.9
Bihar	21.3	27.8	17.2	26.9	76.5	63.8
Chhattisgarh	8.6	10.8	6.3	10	79.3	63.2
Delhi	0.1	5.2	0	5.9	1	0.2
Gujarat	15.7	25.3	12.9	24.7	62.1	52.2
Haryana	5	9.2	4.3	9.6	54.8	44.8
Himachal	2.1	3.3	2.2	3.4	63.6	64.2
J &K	2.8	4.3	2.9	4.7	66.1	61.6
Jharkhand	7.7	11.7	4.9	10.1	65.4	49.1
Karnataka	17.6	27.4	15.3	26.8	64.4	57.3
Kerala	5.1	12.7	4.2	12.9	40.1	32.1
MP	18	28.2	18.4	28.5	63.8	64.4
Maharashtra	22	48.1	26	39.1	45.7	52.9
Orissa	11.2	16.7	10.1	16.2	67.1	62.2
Punjab	3.6	10.7	4.7	10.4	33.6	45
Rajasthan	17.4	26.5	13	27.2	65.8	47.7
TN	14.5	31.3	12.6	30	46.4	41.8
UP	3.3	65.2	39.8	65.9	66.4	60.4
Uttarakhand	2.7	4	2.4	4	68.6	60.5
West Bengal	15.5	31.7	14.8	34.2	49	43.4
Total across states	262.5	449.6	236.1	451.4	234.7	456.8

Additionally, various sensors have been discussed in the literature for measuring environmental parameters [22], [23]. Many researchers worldwide have been focused on implementing wireless sensor networks to monitor parameters such as temperature, soil moisture, and humidity. The paper emphasised the use of technology to improve yield and highlighted different techniques for measuring environmental parameters and communication [7], [22], [24]-[27].

Between the 1970s and 2020 (Table 3), notable climatic changes have been observed, including a consistent rise in surface temperatures, increased atmospheric moisture, and regionally varied trends in relative and soil moisture [28]-[30]. The survey indicates that the number of cultivators and farmers has been increasing over time, contributing significantly to employment. It also highlights a drastic shift in climatic conditions not only in India but globally. These changes, driven by global warming, land-use alterations, and hydrological imbalances, collectively point to an intensifying climate system with wide-ranging impacts on agriculture, water resources, and ecological stability. The temperature has risen by approximately +1.0 °C, relative humidity has increased by around +2.5% globally, and the soil moisture has declined by about –3.0%, indicating increasing drought and aridity trends [31]-[33]. In Table 4 [34], it is very clear that each plant needs specific environmental conditions for proper growth.

The literature survey indicates that studies have been conducted that utilise sensors to measure environmental parameters, and there are various modes through which they can be connected as well. The farmer's requirements are to know which crop needs what environmental parameters and also to ensure that such an environment is maintained. The gap here is that, after understanding the current values of the soil through the sensors, a supportive mechanism is needed to make informed decisions about choosing the crop for that particular environment, measuring the relevant parameters, and adjusting the environmental parameters to ensure the required environment is provided. This issue has been addressed in the proposed work. The authors have designed and developed a system where the farmer enters the crop they want to grow. The system identifies the environmental conditions and informs the former whether it's suitable or not. The system also measures the parameters like temperature, light, rainfall, humidity, moisture, pH value, and takes actions appropriately [15], [21], [35]-[38].

These literature findings reinforce the need for a soil health monitoring system to help farmers improve crop yields. The studies highlight the challenges in agricultural employment and the importance of accurate monitoring systems to bridge the gap between demand and supply. Farmers can make informed decisions and take appropriate actions to enhance productivity and reduce food scarcity by utilizing wireless sensor networks and advanced technology.

Table 3. Climatic changes observed (1970s–2020)

Parameter	Change	Annual rate
Surface temperature	+0.01–0.04 °C per year → ~0.5–2 °C over 50 years	0.5–0.8 °C/decade
Atmospheric moisture (PWV)	Increased by 0.03–0.15 mm/year → ~1.5–7.5 mm overall	0.03–0.15 mm/year
Relative humidity	Mixed regional trends: ↑ ~0–10% per decade, some ↓	~0.5–1%/decade (locally higher in Himalayas)
Soil moisture	↑ in irrigated Indo–Gangetic Plain; ↓ elsewhere	Regional variation
Parameter	Change	Annual rate

Table 4. Optimal environmental conditions, such as temperature and relative humidity (RH), required for different plants [34]

Plant	Day temp (°C)	Night temp (°C)	RH (%)
Tomato	23–27	13–16	50–60
Cucumber	25–30	Not specified	80–90
Eggplant	25–28	14–16	65–75
Pepper	22–30	14–16	60–65
Lettuce	24–28	13–16	65–80
Strawberry	20–26	13–16	50–65
Beans	22–26	16–18	70–80
Peas	25–30	16–18	70–80
Leafy/stem veg (spinach, lettuce) -nutritional quality	10–22 (aerial)	—	Not specified
General indoor foliage	21–27	16–20	40–60
Tropical indoor plants	21–32	≥ 16	60–80
Desert/cacti/succulents	21–29	13–16	10–30
General herbs & veg (non-tropical)	—	—	50–70
Seedlings & cuttings	—	—	70–85

3. METHODOLOGY

Figure 2 depicts the block diagram of the soil health monitoring system. The controller is the main brain of this system. It controls the overall operation of the system. The advanced RISC machine (ARM) microcontroller is interfaced with a keyboard, sensors, a liquid crystal display (LCD), and a global system for mobile communication (GSM). The system has various sensors, including humidity, temperature, moisture, LDR, rainfall detector, and pH sensors. The outputs of these sensors are connected to the microcontroller's input. The various parameters required for a plant to grow have been stored in the system's memory.

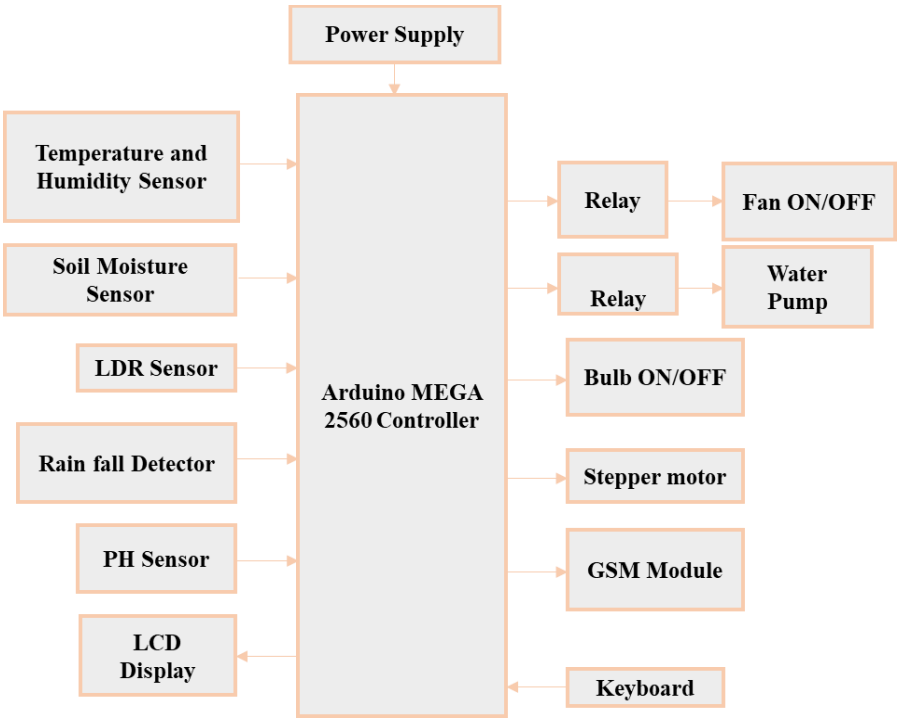

Figure 2. Block diagram of soil health monitoring system

Initially, the farmer is expected to enter the crop he wants to grow. This can be done through the keyboard. The system measures environmental parameters and, if appropriate, suggests them to the farmer. Otherwise, it indicates the crop that is appropriate for those parameters on the display.

The DHT11 is a basic, low-cost digital temperature and humidity sensor that offers high reliability and excellent long-term stability. The light drop resistor (LDR) is used to sense light intensity, which is crucial for plant growth. Low light levels negatively affect plant development, so artificial lighting is used to compensate. In this project, a 100-watt bulb demonstrates this, turning on when light levels fall below a set point, and turning off when light levels are within a normal range, sending a notification to the owner. Soil moisture sensors measure the volumetric water content in soil and provide the moisture level as output. These sensors have both analog and digital outputs, allowing for flexibility in their use. They consist of two probes that measure moisture by passing current through the soil; higher water content results in lower resistance and higher moisture readings, while dry soil conducts poorly and results in higher resistance and lower moisture readings. The rain sensor module features a rain board and a separate control board for convenience, along with a power indicator LED and an adjustable sensitivity via a potentiometer. The analog output detects rainfall drops, with the LED turning on when no raindrops are detected and the digital output (DO) being high. When a small amount of water is detected, the DO output goes low, and the switch indicator activates. Soil pH, which influences plant growth by affecting nutrient absorption, is measured on a scale of 0-14. A pH below 7 is acidic, above 7 is basic, and 7 is neutral, which is optimal for many plants. Monitoring pH values and taking appropriate actions can help farmers improve their crop yields.

In this work, a mini water pump has been used. It can deliver up to 120 liters per hour with very low current consumption of 220mA. The relay is used to connect and disconnect the supply based on the conditions provided to its control winding. Once the seeds are planted or saplings are transplanted, the crop grown is fed to the microcontroller through the keyboard. The sensors are connected both to the system and

the field. The microcontroller receives sensor values and compares them with the predefined values stored in memory for that particular crop. Whenever the measured value deviates from the predefined value, the controller switches the appropriate devices on or off as needed. Simultaneously, the microcontroller sends information via the GSM modem to the farmer, allowing him to take necessary action.

Eventually, the deviation is evaluated based on current values and data stored in memory. Depending on the deviation, it takes appropriate actions, such as turning the fan, motor, and light on or off. It also sends information and GPS location to the relevant authorities. These authorities can offer guidance on the actions farmers should take. This helps farmers identify problems and act with expert advice. Ultimately, this leads to higher production and increased yields, helping producers achieve better financial stability. Additionally, the system conserves water and energy.

When the system is turned on, a message "Krushika Snehi" appears on the LCD as a welcome note. The device measures environmental parameters and suggests the most suitable crop, then sends this information to the farmer. The farmer plants the saplings and connects the sensors and devices. The sensors detect parameters such as temperature, humidity, soil moisture, and light. These values are sent to the controller, which displays them on the LCD screen. The same information is also sent to the farmer via GSM. When the values fall outside the reference range, the controller takes appropriate action. The DHT11 sensor detects temperature; if it exceeds the threshold, the fan turns on. If it is below the threshold, the fan turns off. Similarly, if humidity exceeds the threshold, the motor turns on; if it is lower, the motor turns off. The LDR sensor detects light; if it is low, Arduino turns on the light; otherwise, the light remains off. The FC 28 moisture sensor measures soil moisture; if it is below the threshold, the motor turns on; if it exceeds the threshold, the motor turns off. The rain sensor detects water content; if it indicates heavy rain, the shutter is closed using a stepper motor. If it is not raining heavily, the shutter remains open. All this information is transmitted to farmers through the GSM module (Figure 3).

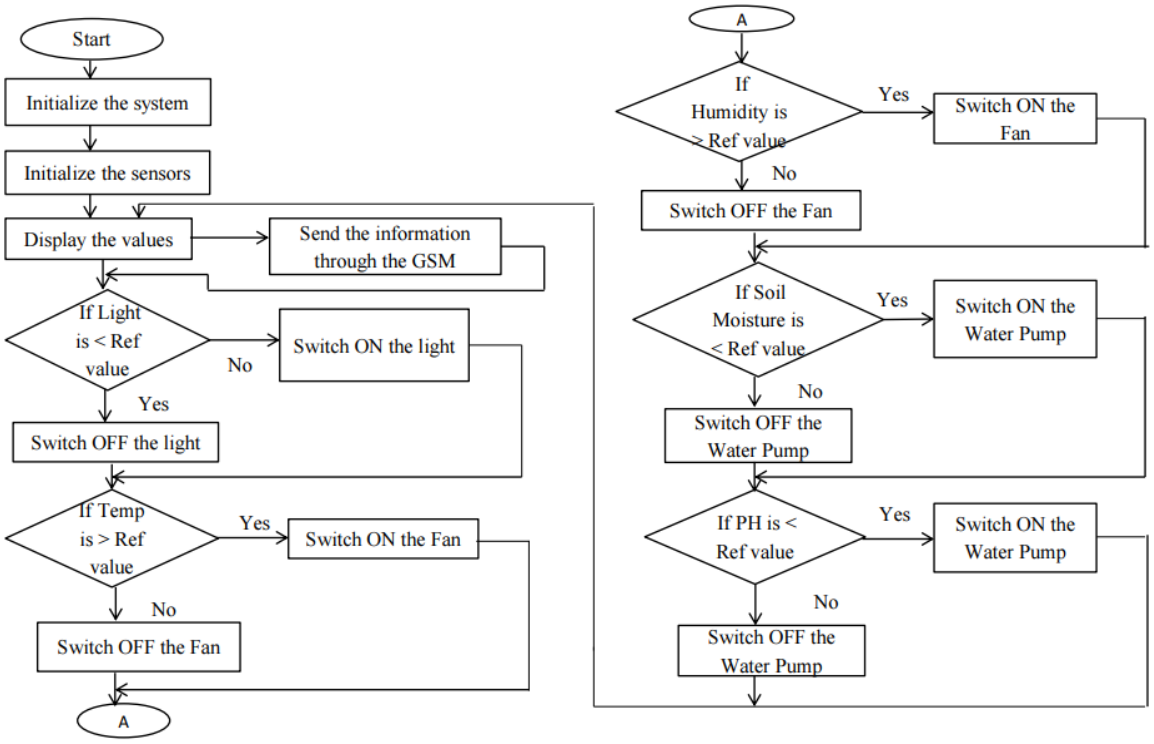

Figure 3. Flowchart of the proposed system

4. RESULTS AND DISCUSSION

The challenges faced during the design of this system involved selecting the right sensors. Choosing appropriate sensors and switching devices compatible with the output devices was a crucial part of the design process. This was addressed by creating a list of all necessary sensors and verifying their specifications, functionality, and other relevant details. The overall prototyping became feasible by testing each sensor individually in the laboratory, checking the output values, and programming the Arduino for different

threshold levels based on the requirements. Calibration was performed wherever necessary, both in hardware (using a Potentiometer) and in software (setting the threshold values). Likewise, output devices such as the fan and motor were tested individually by adjusting the threshold values in the code. Both hardware and software were modified to meet the prototype's requirements. After testing the individual sensors and output devices, the overall functionality of the module was evaluated.

Figure 4 shows the flowchart of the proposed system. When the system is turned on, a message "Krushika Snehi" is displayed on the LCD, indicating a welcome note. The sensors detect parameters like humidity, temperature, light, and soil moisture. These values are transmitted to the controller. The controller displays these values on the LCD screen. The same information is transmitted to the farmer via GSM. Whenever the values are below or above the reference, the controller takes the necessary action. DHT11 is a simple, incredibly affordable digital temperature and humidity sensor.

It measures the ambient air using a thermistor and a low-loss humidity sensor, then emits a digital signal on the data pin. Although it's relatively easy to use, capturing data in a timely manner is crucial. This DHT11 sensor detects the temperature value, and if the temperature exceeds the threshold value, the fan will be turned on. The fan will be turned off if the temperature is below the threshold value. The motor will be turned on if the humidity exceeds the threshold value. The motor will be turned off if the humidity is below the threshold value. The LDR senses the light. The controller will turn on the light if the reading is below the threshold; otherwise, the light will be turned off. One of the most effective and reasonably priced sensors is the FC-28 soil moisture sensor.

General working logic: The difference in tension between the electrodes on the sensor is caused by the resistance of the environment. It provides information about the moisture level in the atmosphere. This FC 28 moisture sensor detects the soil moisture content. The motor will be turned on if the soil moisture is below the threshold value. If the moisture in the soil is above the threshold value, the motor will be turned off. The rain sensor detects the amount of water present. If there is heavy rain, the plants will be damaged. To address this issue, the controller activates the stepper motor, which then covers the area where the plants are grown using a shutter. The system transfers sensor data via IoT technology to a cloud-based platform, which is then evaluated and used to provide farmers with real-time recommendations. All this information is transmitted to farmers via a GSM module. The same information is sent to experts for their advice, and the proposed model's test results are presented in Figures 4(a)-4(c). Unlike the results of [OBJ], which mainly focus on a single parameter to assess soil condition, this system's output considers multiple factors like temperature, humidity, pH value, light, soil moisture, and moisture.

(a) (b) (c)

Figure 4. The test result: (a) proposed system test results, (b) soil moisture output, and (c) rain sensor output

5. CONCLUSION

This study presents an IoT-based system designed to monitor and control various environmental factors essential for agriculture. It ensures optimal conditions for crop growth by effectively detecting changes in temperature, humidity, light, soil moisture, and rainfall. The system reacts to these changes by taking actions that preserve ideal conditions vital for plant health. By providing farmers with real-time data and automated controls, the system enables them to make informed decisions that can boost crop yields and conserve resources. The results demonstrate that the system accurately measures environmental parameters and implements appropriate control measures. Adopting an IoT-based system can greatly enhance agricultural efficiency and sustainability. In future research, efforts could focus on further optimizing crop management by adding parameters such as nutrient levels and pest detection. This approach could lead to a more comprehensive strategy for maintaining soil health and encouraging sustainable farming practices.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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